Document 2

ASSESSMENT OF THE PACIFIC SARDINE RESOURCE IN 2009 FOR U.S. MANAGEMENT IN 2010

Prepared for
WORKSHOP ON ENHANCING STOCK ASSESSMENTS OF PACIFIC SARDINE IN THE CALIFORNIA CURRENT THROUGH COOPERATIVE SURVEYS
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I. Background

The Pacific sardine resource is assessed every year in support of the Pacific Fishery Management Council (PFMC) process to establish a harvest guideline (HG) for the U.S. fishery. The current assessment was conducted using the Stock Synthesis (SS) model (Methot 2005, 2009), and includes fishery and survey data from updated and new sources. The draft assessment was reviewed by a STAR Panel 21-25 September, 2009, in La Jolla, California. During the STAR, modifications to input data and model structure were incorporated. The final base model was presented to the PFMC's advisory bodies (SSC, CPSMT, CPSAS) and the PFMC at their November 2009 meetings in Costa Mesa, CA. The outcome of these reviews formed the basis for U.S. Pacific sardine management in 2010. The full assessment and advisory body reports were published in a NOAA Technical Memorandum (Hill et al. 2009): http://swfsc.noaa.gov/publications/TM/SWFSC/NOAA-TM-NMFS-SWFSC-452.pdf.

II. Stock Assumptions

The Pacific sardine (*Sardinops sagax caerulea*) is thought to comprise three subpopulations. In this assessment, we model the northern subpopulation which ranges seasonally from northern Baja California, México, to British Columbia, Canada, and as far as 300 nm offshore. All U.S., Canada, and Ensenada (México) landings are assumed to be taken from a single northern stock. A portion of the sardine caught in the Southern California Bight (Ensenada to Santa Barbara) may originate from the southern subpopulation centered off the Baja California Peninsula. Future modeling efforts will explore scenarios that separate the catches in Ensenada and San Pedro into the respective northern and southern subpopulations using objective criteria such as temperature-at-catch or otolith morphometric analyses.

III. Fishery-Dependent Data

The assessment includes landings and biological sample data from four commercial fisheries: Ensenada ('ENS'; northern Baja California), Southern California ('SCA'; San Pedro to Santa Barbara), Central California ('CCA'; Monterey Bay area), and the Pacific Northwest ('PNW'; Oregon, Washington, and British Columbia), from July 1981 to June 2009. Landings by fishery, model year (July-June) and semester are presented in Figure 1. State agency port samples were used to derive length and age-at-length compositions for each fishery and semester, as well as a pooled estimate of weight-at-length for converting population numbers to biomass in the model.

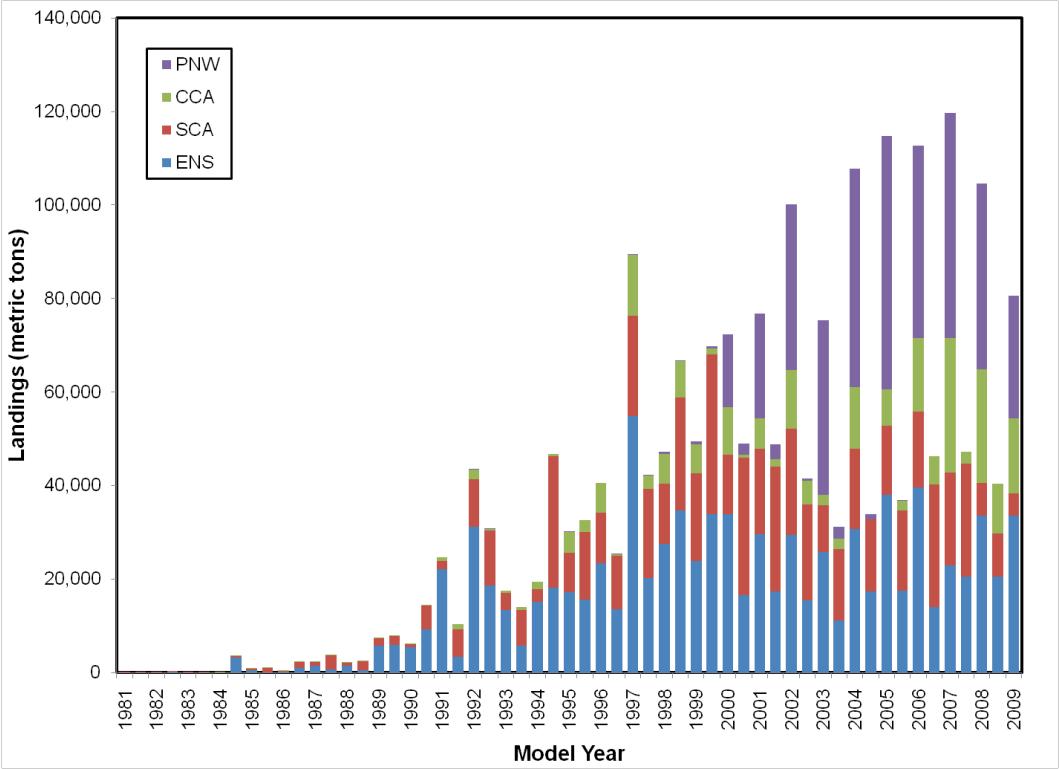

Figure 1. Pacific sardine landings (mt) by fishery, model year and semester.

IV. Fishery-Independent Data

SFWSC Egg Production Surveys

Two fishery-independent time series have been used in recent assessments (Hill et al. 2007, Hill et al. 2008) and both were based on the SWFSC's egg production survey conducted each spring from San Diego to San Francisco. The daily egg production method (DEPM) index of female spawning stock biomass (SSB) is used when adult daily-specific fecundity data are available from sardine collected during the survey. The total egg production (TEP) index of total SSB is used when trawl samples for adults are unavailable, and is simply the product of egg density (P_0) and spawning area (km^2) (Lo et al. 2009). Both time series were treated as indices of relative abundance, where the catchability coefficient (q) was estimated.

SWFSC's egg production survey design and estimation methodology were reviewed by a STAR panel in May 2009. The panel made specific recommendations for modifying past estimates and improving standard estimation procedures across the complete time series. As a result, raw data and procedures from all past surveys were fully re-examined for this assessment. A complete description of these changes is provided by Lo et al. (see Appendix I of Hill et al. 2009). New DEPM and TEP estimates, presented in Figure 2, were used in all model runs this year. The September 2009 STAR panel reviewed these revisions and adopted the new DEPM and TEP values for use in the final model.

West Coast Aerial Sardine Survey of 2009

The Pacific sardine industry funded an aerial sardine survey ranging from Monterey to the northern border of Washington during summer of 2009. The 2009 survey was built upon methods developed during a pilot study conducted in 2008. The overall approach was reviewed and refined by a STAR panel held in May of 2009. The 2009 survey employed two sampling elements: 1) high-resolution photographs collected by spotter planes to estimate the number and surface area of sardine schools, and 2) using fishing vessels to conduct point sets on schools to determine the relationship between surface area and biomass and to determine size composition of the schools. A complete description of the methods and results is provided by Jagielo et al. (2009).

The 2009 survey results were reviewed during the September 2009 STAR panel. The Panel made numerous recommendations for analysis throughout the week, resulting in refinement of the survey estimate and associated CV. The Panel ultimately endorsed the 2009 aerial survey estimate of 1.35 million mt (CV=0.55) for use in the stock assessment model. A length composition for the survey was fit using a dome-shaped selectivity function. The estimate was fit with a catchability coefficient (q) of 1. The final base model was tuned prior to adding the aerial survey estimate.

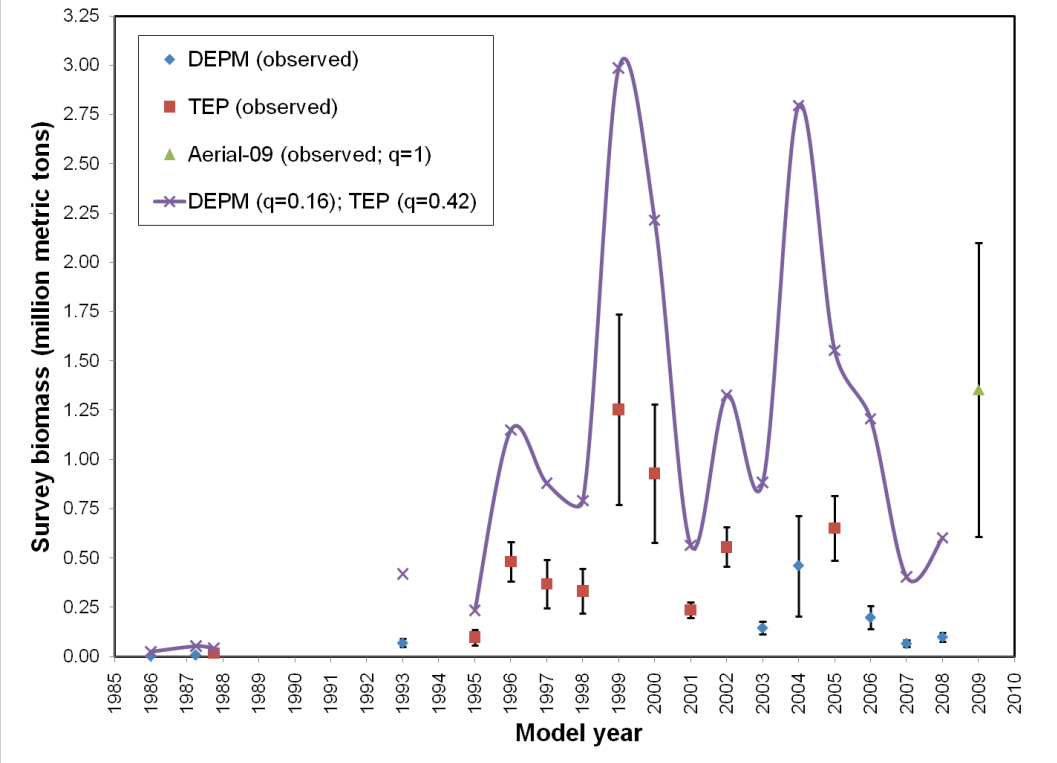

Figure 2. Estimates of Pacific sardine abundance from the egg production and aerial surveys. When the aerial survey estimate was included with q fixed at 1, q for the DEPM series (female SSB) was estimated to be 0.1645. The TEP series (total SSB) was best fit with q=0.4195.

V. Final Model Specifications

The assessment was conducted using Stock Synthesis version 3.03a (Methot 2005, 2009). The final base model had the following specifications:

- Model Year based on the July 1 birth date assumption (July 1-June 30 time span);

- Assessment years 1981-2009; Two semesters per year (S1=Jul-Dec; S2=Jan-Jun);
- Four fisheries (ENS, SCA, CCA, PNW); annual selectivity patterns for ENS and PNW and seasonal selectivity patterns for SCA and CCA (S1 & S2).
- Use of length-frequency and conditional age-at-length data for all fisheries;
- Length-based, double-normal (domed-shaped) selectivity with time-blocking:
    - ENS, SCA_S1, & SCA_S2: 1981-91, 1992-98, 1999-09;
    - CCA_S1 & CCA_S2: 1981-92, 1993-98, 1999-09;
    - PNW: 1981-03, 2004-09;
- Growth estimated for two periods: 1981-90 and 1991-09;
- Natural mortality $M = 0.4\text{yr}^{-1}$ for all ages and years;
- Hybrid-F fishing mortality option;
- Ricker stock-recruitment function; Initial recruitment offset (R_1) estimated;
- DEPM and TEP series of SSB (1986 to 2009) included with q estimated; 2009 aerial survey estimate of abundance included with $q = 1$.

VI. Assessment Results

1. Fit to surveys

The 2009 aerial survey observation was higher than recent biomass from the DEPM and TEP surveys (e.g., 2006-2008), and this scaled model estimates of biomass upward to a considerable extent. Because of this contrast in scale among data sources, the base model was first tuned without the aerial spotter estimate. Once tuned, the aerial estimate was included, without subsequent retuning, to derive final base model results. The base model estimate corresponding to the 2009 aerial survey estimate of selected abundance was outside of the lower 99% confidence interval for the estimate. This discrepancy would be lessened if the survey composition were to be fit with an asymptotic rather than dome-shaped selectivity.

2. Spawning biomass and recruitment

A time series of total SSB estimates is shown in Figure 3. SSB peaked at approximately 1.4 million mt in 2000 and subsequently declined to 530,000 mt in 2009. Virgin SSB (S_0) from the final model was estimated to be 1.03 mmt. Addition of the aerial survey datum scaled SSB considerably upward and increased uncertainty around the estimate. The time series of recruit (age-0) abundance is also provided in Figure 3. Virgin recruitment (R_0) was estimated at 4.94 billion age-0 fish. Recruitment increased rapidly through the mid-1990s, peaking at 16.79 billion fish in 1997, 22.01 billion in 1998, and 18.62 billion fish in 2003. Recruitments have been notably lower since 2006 (Figure 3).

3. Stock biomass (ages 1+) estimate for management

Stock biomass, used for establishing the annual HG, is defined as the sum of the biomass for sardines aged 1 and older. Final model estimates of stock biomass are shown in Figure 4 (blue line). Stock biomass increased rapidly through the 1980s and 1990s, starting at 8,210 mt in 1981 and peaking at 1.69 mmt in 2000. Stock biomass has subsequently declined to the present (July 1, 2009) level of 702,024 mt.

Stock biomass estimates from the final model were compared to final values from recent assessments used for management in 2008 and 2009 (Figure 4). Stock biomass from the 2009 final model (w/Aerial) was very similar to results from the final 2007 assessment. Both the 2009-Base and final 2007 models scaled higher than the 2008 update and the 2009 base model that excluded the aerial survey (Figure 4).

4. Exploitation status

Exploitation rate is defined as calendar year catch divided by total mid-year biomass (July-1, ages 0+). Exploitation rate was relatively high during the early recovery period (mid-1980s) but declined and stabilized as the stock underwent the most rapid phase of recovery. Exploitation rate has subsequently increased in recent years as the stock has again declined. Ensenada catch during 2009 is unknown (unavailable), so is assumed the same as 2008. Total exploitation rate for the combined fisheries is currently less than 16%.

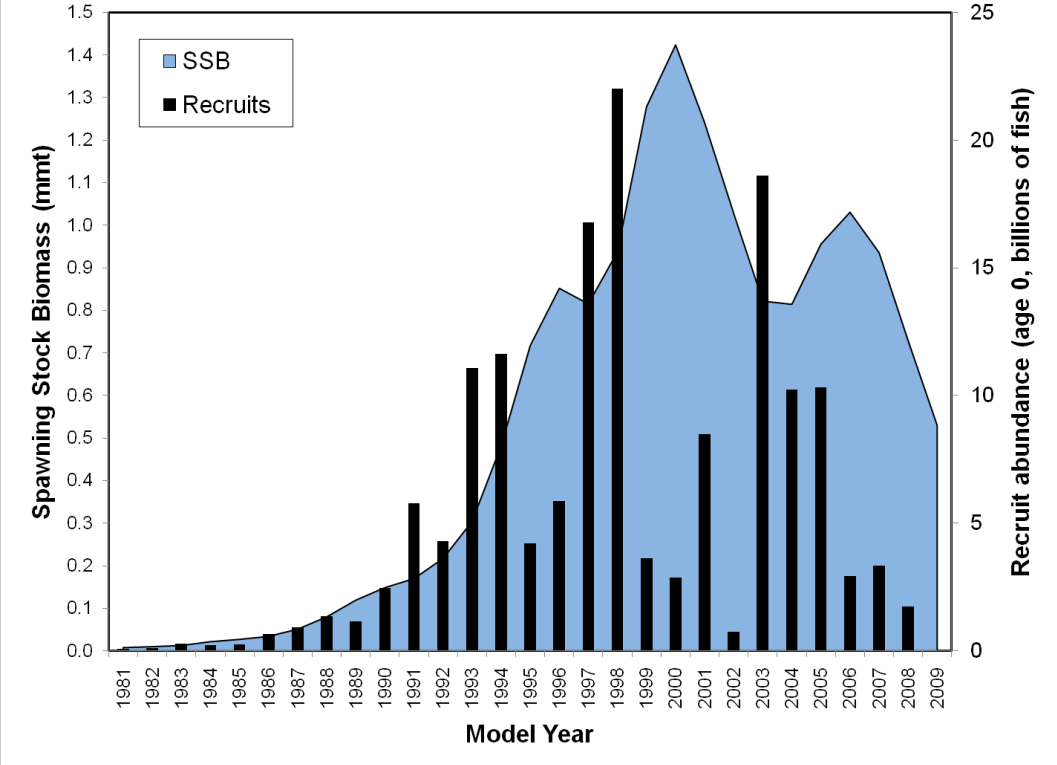

Figure 3. Spawning stock biomass and recruits from the final base model.

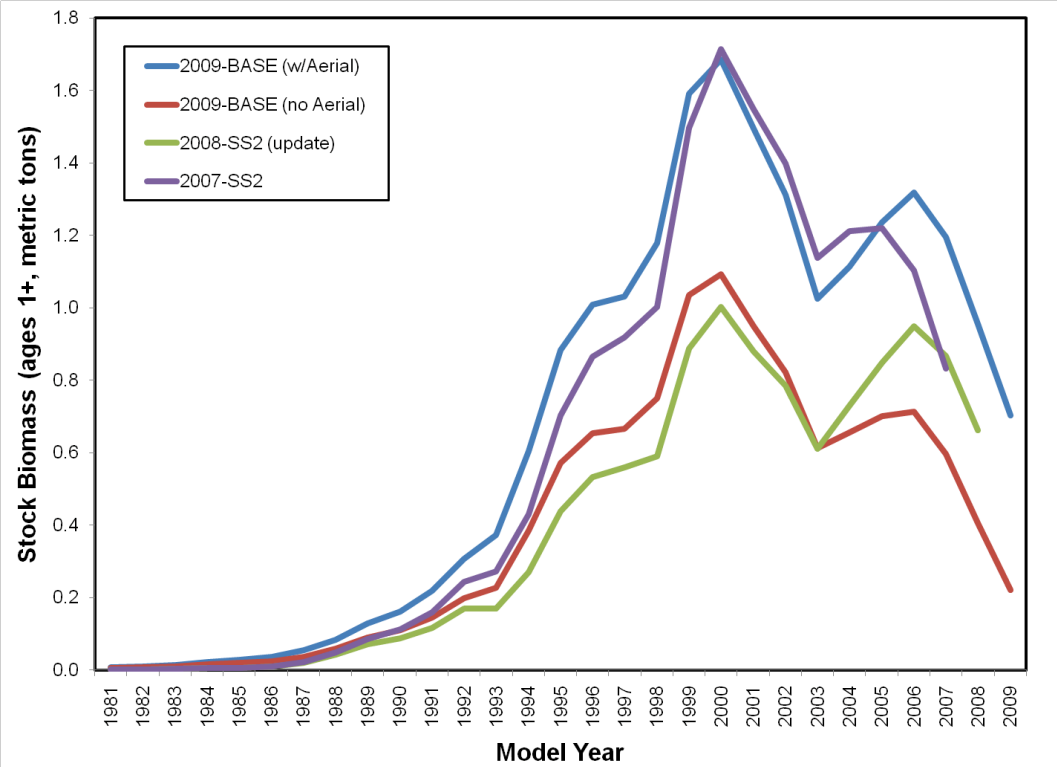

Figure 4. Pacific sardine stock biomass (ages 1+) from the 2009 base model (with and without the 2009 aerial survey) compared to the 2008 update and 2007 final models.

VII. Harvest Guideline for 2010

Based on results from the final base model, the harvest guideline for the U.S. fishery in calendar year 2010 was set at 72,039 mt (Figure 5). The HG is based on the control rule defined in the CPS-FMP:

$$HG_{2010} = (BIOMASS_{2009} - CUTOFF) \bullet FRACTION \bullet DISTRIBUTION;$$

where HG_{2010} is the total USA (California, Oregon, and Washington) harvest guideline in 2010, $BIOMASS_{2009}$ is the estimated July 1, 2009 stock biomass (ages 1+) from the assessment (702,024 mt), CUTOFF is the lowest level of estimated biomass at which harvest is allowed (150,000 mt), FRACTION is an environment-based percentage of biomass above the CUTOFF that can be harvested by the fisheries, and DISTRIBUTION (0.87) is the average portion of BIOMASS assumed in U.S. waters. Based on the current (T_{2009}) SST estimate of 17.92 °C, the F_{msy} exploitation fraction remained at 0.15.

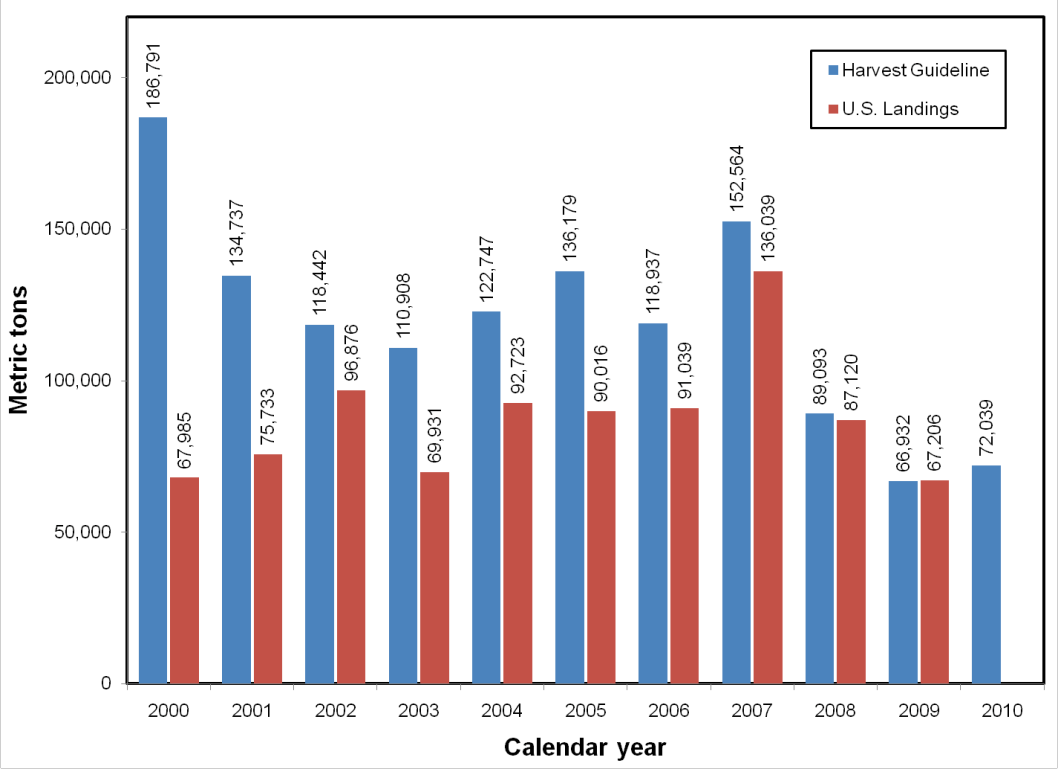

Figure 5. Performance of the U.S. Pacific sardine fishery since calendar year 2000.

VIII. Research and Data Needs

The following recommendations pertaining to sardine surveys are excerpted from the latest STAR panel report (STAR 2009):

- Future assessments should consider the fishery-independent mid-water trawl surveys off the west coast of Vancouver Island. This data set needs to be analyzed further before it can be included in a future assessment. If necessary, the lead investigator from CDFO should be invited to attend the next STAR Panel to present results for this time series.
- Further review the sampling protocols and analysis methods for other potential indices of abundance (such as the SWFSC juvenile rockfish survey and the SWFSC acoustic surveys, which have been conducted in conjunction with egg surveys since 2003) should be conducted and inclusion of such data in future assessments should be considered.

- There continues to be uncertainty in the DEPM survey as a key indicator of spawning stock biomass trends coastwide. Attempts should be made to expand coastwide sampling of adult fish to further refine the estimate of the proportion spawning.
- Spatial models for Pacific sardines should be considered. These can be used to explore the implications of regional recruitment patterns and region-specific biological parameters. These models could be used to identify critical biological data gaps.
- The method of variance estimation to account for all sources of uncertainty in the aerial survey should be refined. Specifically, methods (e.g., bootstrapping) should be indentified that can take into account: (a) inter-transect variation in density, (b) uncertainty about the school weight – school area relationship, (c) variation for individual schools about the school weight – school area relationship, and (d) uncertainty arising from attempting to estimate the size of schools.
- Protocols used to distinguish sardine and non-sardine schools in aerial survey photographs should be defined.
- Methods (e.g. acoustics) that can be used to determine the proportion of sardine schools that are visible from aircraft should be considered, including whether it is possible to use acoustics to calculate the density associated with schools that are too large to be sampled using point sets.

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